

ECOLOGY

DISTRIBUTION OF HUMUS, ROOT-SYSTEMS AND SOIL
INVERTEBRATES WITHIN THE SOIL OF THE WALNUT
FORESTS OF THE FERGHANA MOUNTAIN RANGE

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In 1945 I was engaged in a study of the soil fauna of the walnut and fruit-tree forests covering the Ferghana mountain-range (silviculture station Kara Alma, Jalalabad province, at an altitude of 1450 m above sea level). It was pointed out by Prof. D. G. Vilensky as early as in 1944 that the thick strata of structural soils rich in humus, which form the floor of those forests, and which this writer classed as burozem varieties specific for the given territory, developing under the most xeromorphic conditions for the soils of this type, are formed under active participation of soil fauna, in the first place, of earthworms.

In order to evaluate the rôle played by the soil fauna in the formation of these soils, and the conditions under which the process took place, it appeared necessary to compare the vertical distribution of soil animals with the thickness of the corresponding genetic horizons of the soil, and their humus contents, as well as with the distribution within them of root systems.

The investigation was carried out on a plot of old walnut forest (*Juglandetum*), of a dense stand, with *Impatiens parviflora* and *Geranium* being prevalent in the herbaceous layer, directly underneath the walnut trees, and grasses (*Brachypodium silvaticum*, etc.), inbetween the trees.

The accumulative humus horizon attains a great thickness (60—75 cm) in this part of the forest. A layer of dead litter (A_0), which was about 1 cm thick by the end of June, overlays the dark-grey, somewhat brownish horizon A_1^* , with a well-pronounced, fine nut-like structure extending to a depth of 13 cm.

This horizon is strongly penetrated by roots, and pervaded by passage-ways of insects and other invertebrates. Horizon A_2 (13—38 cm) is also dark-grey, and somewhat denser than horizon A_1 . This layer is to a lesser extent penetrated by roots, and not so closely pierced by holes bored by invertebrates. Horizon A_3 (38—60 cm) is lighter, with a clearly pronounced brownish tinge, and a prismatically nut-like structure. Horizons A_1 and A_2 are loamy, horizon A_3 consists of heavy loam.

Horizon A_4 , up to 77—82 cm downwards, is brownish-grey, heavy loam, with a granular fine nut-like structure. Both number of roots, and density of passage-ways decrease appreciably with depth. Horizon B_1 is rusty-brown, with a slightly pronounced granular structure. The boundary separating horizon B_1 from the soil-forming rock (C) is sharply marked, passing at a depth of 115—130 cm.

Horizon C is made up of a pale-yellow loess-like loam, holding shells of land gastropods (*Pupa* and others), common to loess.

According to data by Vilensky, the content of humus, as determined

* Within the limits of the accumulative humous horizon (A) the transition between the separate layers is so gradual that the whole horizon should perhaps more conveniently be considered as $A_1(A_1', A_1'', A_1''')$.

by Knop's method, is 10.45 per cent in the 5—10 cm layer, 7.54 in the 16—21 cm layer, 3.27 in the 35—40 cm layer, and 1.94 per cent, at a depth of 60 cm. The mode of distribution of the humus throughout the soil coincides with the distribution in the soil of the root systems (Table 1).

In horizon A₁ is concentrated the bulk of roots, not only of those of herbaceous plants, but of the walnut-trees, as well. An interesting feature of the root system of the walnut in South Kirghizia consists in a network of feeding rootlets developed in the upper soil layer, which, instead of being directed downwards as in most plants, are directed upwards. These thin feeding rootlets are sent off by thicker horizontal roots; they extend to the surface of the soil, to the litter. Their absorbing white endings are at work throughout the damp spring-summer period (which lasted until early in July under the conditions of the rainy summer of 1945); they are getting black and rotting towards the middle of summer, when the weather is droughty. More powerful, infixing roots of the walnut tree are mostly distributed within the 30—60 cm layer. The root system of most herbaceous plants do likewise attain a depth of 60—70 cm. Thin feeding roots of the walnut tree reach a considerable depth, branching profusely at the line of transition between B₁ and C, but penetrating much below it (Table 1).

Table 1
Quantitative Distribution of the Root Mass According to Soil Horizons*

Horizon	Depth, in cm	Volume of roots in cm ³ per 1 dm ³ soil	Weight of roots in g per 1 dm ³ soil	
			of walnut tree	of grasses
A ₁	0—13	14.5	6.1	0.8
A ₂	13—38	6.3	2.5	0.2
A ₃	38—60	3.2	0.3	0.1
A ₄	60—82	1.0	0.5	0.01
B ₁	82—115	1.0	0.2	0.01

The vertical distribution of soil animals was found to vary as to the season. Until late in June, while in the upper layers the soil was still saturated with moisture up to 90 per cent to the total water-holding capacity, the population of the soil was crowded in the upper portion of horizon A₁, close to the very surface of the soil. Even such geobionts, as the earthworms (mostly of the genus *Eophila*), myriapods, larvae of *Selatosomus lemniscatus* Denis. etc., participated actively in litter decomposition.

As soon as the rainy period was over, all these soil invertebrates began to migrate deeper into the soil.

The main agent, responsible for the summer-migration of invertebrates to the depth of the soil is the drying of the upper soil layers, whereas the maximum depth of migration depends upon the conditions of aeration. The phytophagi are less dependent upon soil moisture, for they are able to compensate the moisture deficiency by feeding on succulent roots. Saprophygy becomes impossible in a dry substratum, and therefore the relation between the dwelling-place and soil moisture is more sharply pronounced in saprophagi, especially in earthworms. In 1945 soil invertebrates were found to migrate not too deep; deeper than the rest penetrated the earthworms, chambers with tangles of earthworms were found at a depth of no more than 60 cm.

Less obligatory saprophagi could but seldom be traced to a depth of 50—60 cm, being concentrated in horizons A₁ and A₂ during the droughty season, too. Thus even at the droughty period of the summer the most densely popu-

* Determinations made by N. A. Pankova, by the method of sieve washings.

lated layer of the soil in walnut and fruit-tree forests is the humous horizon (A_1 and A_2), i. e. in the case of pure walnut forests the most overcrowded are layers 0—13 and 13—35 cm deep, as may be seen from Table 2.

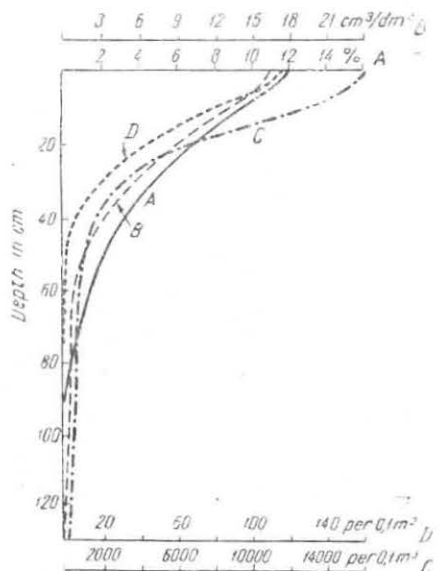
Larger soil invertebrates—the mesofauna—were recorded by the method of entomological soil sampling of successive layers. Smaller organisms, such as mites and springtails, were recorded by the method of automatic selection, made with the aid of Berlese-funnels. The latter had been somewhat modified by the author, according to the needs of our highland expedition, and to the necessity to use sun drying (^{1,3}).

The degree of decomposition of the organic remains in the upper soil layers and in the litter, and the disappearance of dead leaf litter as early as by the middle of the summer season, are largely de-

Table 2

Vertical Distribution of Soil Invertebrates During the Dry Period of the Growing Season (July—August 1945)

Depth of layer investigated, in cm	Number of invertebrates in a soil layer 1 dm thick, per 1 m ² of the area	
	Mesofauna*	Microfauna**
0—10	110	14 800
10—20	50	11 700
20—30	38	4 100
30—40	8	—
40—50	4	900
50—60	1	1 400
100—110	single specimens	1 000
150—160	none	single specimens



Vertical distribution of humus, of root systems, micro- and mesofauna within the soil under the walnut forest of the Ferghana mountain-range; A, humus; B, root systems; C—microfauna; D, mesofauna.

pendent on the feeding activity of soil animals, whose burrowing activity contributes greatly to a better aeration and water percolation of the soil.

The soil layer which is most densely channeled by passage-ways is horizon A_1 , which gives shelter to the total animal population of the soil during the wet season, and to most of it during the arid period of the summer, too. The lower limits of the humous horizon (A) coincide with the depth to which the bulk of earthworms penetrate into the soil.

The limits of horizon B_1 , which is also pierced by passage-ways, though to a lesser degree than the higher horizons, coincide with the depth to which individual earthworms are able to penetrate during especially arid seasons.

As to the passage-ways observed at a greater depth, on account of aeration conditions, these cannot be due to the recent burrowing activity of earthworms. As shown by our special investigations, these passage-ways are often but traces of decayed roots, afterwards eaten through by minute arthropods. The latter (mites, spring tails), because of their negligible mass, consume smaller quantities of oxygen than the much larger earthworms and insect larvae, owing to which they are able to penetrate to poorly aerated soil layers, at a depth exceeding 150 cm. Thus in the boring of passage-ways in the upper layers take part all soil animals (both meso- and microfauna), while at a depth below 100—120 cm, the microfauna alone.

* 3 records, sample area 10 m²; ** 4 records, 1 cm² from the layer.

By comparing the vertical distribution of soil animals with the distribution of root systems and the humus content in the soil, we are able to bear out certain regularities (see figure).

The structural soil horizons of walnut and fruit-tree forests, which are the highest in humus and also the most abundantly pervaded by passage-ways, are also the richest both in vegetable roots and in fauna. Within horizon A_1 is concentrated the main bulk of the supplying roots of the walnut trees, which extend upwards to the litter, as well as the main mass of roots of herbaceous plants; this horizon is also the most densely populated one. Within this horizon takes place the decomposition of shedding leaves, mixed to the soil, a process in which the soil fauna plays an important part. The bottom-most boundary of the humous horizon (60—70 cm) coincides with the lower boundary of distribution of the main bulk of the thickest walnut roots, with the boundary of penetration of roots of most herbaceous plants, with the boundary of penetration of soil invertebrates, and with that of well aerated layers of the soil during the arid season of the year.

All these limits show a definite correlation⁽²⁾. The accumulation of humus in the soil is connected with the development in it of root systems, and with the admixture of dead leaves to the soil, which materials serve as the main source for humus formation, and with their decay, which proceeds under active participation of the soil fauna.

The distribution of root systems within the soil is connected with the thickness of the humus horizon: the plants consume the salts that are forming in the course of mineralization of organic remains. The penetration of roots to a great depth is facilitated by passage-ways, bored by soil animals.

The limits of the vertical distribution of animals in the soil are connected with the boundaries of its saturation with root systems (for phytophagi), and with humus (for saprophagi). Thus all the links of the dynamical soil complex—root system—soil fauna (and of course microflora, too)—humus—are correlated with one another.

Within the zone of the walnut forests of Mountainous South Kirghizia this correlation becomes especially clear cut at the wet period, early in summer. When the loess becomes oversaturated with moisture, the activity of soil animals and of aerobic microorganisms is prevented there because of air deficiency. All processes of decay and mineralization of the dead leaves proceed therefore mostly at the surface of the soil, where the whole of the soil fauna is concentrated. This seems to account for the peculiar features of the root system of the walnut trees which send to the litter their vertical feeding roots. Under conditions of poor aeration, the latter assimilate the nutrient substances from the decaying litter. As the soil dries up and aeration becomes better, the processes of decomposition of the organic matter brought to the soil by invertebrates, especially by earthworms, penetrate deeper, where the products of their mineralization are assimilated by deep-seated roots,—the lower limit of the main feeding roots thus coincides with the boundary of aerated soil layers.

The increase in the density of the soil fauna which is the main agent improving the aeration of the soil of a given mechanical composition, contributes to the development of a thicker humous structural horizon. The thickness of the latter in walnut forests of the Ferghana mountain-range is undoubtedly associated with the dense population of the soil by invertebrates, and with their active vertical migrations, which are caused by the continental climate conditions.

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